DENSITY AND POROSITY MEASUREMENTS OF LUNAR AND MARTIAN MATERIALS. R. J. Macke[1], W. S. Kiefer[2], A. J. Irving[3], D. T. Britt[4,5] [1]Vatican Observatory, V-00120 Vatican City State, rmacke@specola.va; [2]Lunar and Planetary Institute, 3600 Bay Area Blvd, Houston TX 77058, kiefer@lpi.usra.edu; [3]University of Washington Department of Earth & Space Sciences, Seattle WA 98195, irvingaj@uw.edu; [4]University of Central Florida Department of Physics, 4111 Libra Dr, Orlando FL 32816, britt@physics.ucf.edu; [5]Center for Lunar and Asteroid Surface Science, 12354 Research Pkwy Suite 214, Orlando FL 32826.

Introduction: As part of an ongoing study [cf. 1,2] to improve the interpretation of gravity data from instruments on lunar and martian orbiting spacecraft such as GRAIL [e.g. 3,4], in order to better characterize the crust of those bodies, we have been conducting a study of the density and porosity of lunar and martian crustal materials. In the case of the Moon, samples from the Apollo lunar missions provide geologic context, whereas lunar meteorites expand the breadth of materials that we can sample. In the case of Mars, we are limited for now to meteorites. Fortunately, in recent years the number of lunar and martian meteorites available for study has grown considerably [cf. 5,6].

This past year, we added several measurements both from the Apollo collection and the meteorite specimens under study at the University of Washington, many of which are type specimes from the UWB repository at the Burke Museum or the Planetary Studies Foundation repository. We summarize here new data from 16 Apollo rocks, 35 lunar meteorites, and 14 martian meteorites. These add to our existing database of 126 lunar and 39 martian specimens. Several of the new specimens sample lithologies that had been missed or underrepresented in earlier data. The new samples fill important gaps in our database; for example, they provide a more complete suite of impact breccias from the Apollo 16 and 17 landing sites.

Measurement: Measurements were performed onsite at NASA Johnson Space Center in Houston, and at the laboratory of A. Irving at the University of Washington campus in Seattle. We used fast, nondestructive and non-contaminating methods for all measurements. Bulk density was determined by 3-D laser scanning utilizing a NextEngine ScannerHD [cf. 7]. Grain density was measured with helium ideal-gas pycnometry using a Quantachrome Ultrapyc 1200e. In a few cases where samples did not fit in the Ultrapyc, we used a custom-built pycnometer with a larger primary chamber [8]. Porosity was calculated from bulk and grain densities: $P = 1 - (\rho_{bulk} / \rho_{grain})$. We also measured magnetic susceptibility using a ZH-instruments SM30 device, correcting for small sample volumes according to [9].

Results:

Lunar meteorites and Apollo moon rocks: We add measurements for 33 anorthositic and feldspathic specimens, three impact-melt breccias, six basalts and basaltic breccias, eight other breccias, and one olivine gabbro.

For grain densities, most of the samples group with previously measured specimens between 2.7 and 3.1 g cm^{-3} for feldspathic breccias and anorthosites, and between 3.2 and 3.4 g cm^{-3} for basalts. The feldspathic breccia Northwest Africa (NWA) 7959 is an exception with a low grain density of 2.59 g cm^{-3}. Regarding porosities, most basalts are under 10% porous, and breccias are between 0 and 20% [Fig. 1]. The Apollo feldspathic breccias 67015 and 67016 have exceptionally lower bulk density than average, with correspondingly high porosities of about 25%. These samples were collected on the rim of North Ray crater and are the deepest samples collected from the Descartes formation, which was likely ejected during the Imbrium-basin forming impact. Our measurements of 67015 and 67016, based on 4 subsamples totaling 60 gm, are tighty clustered.

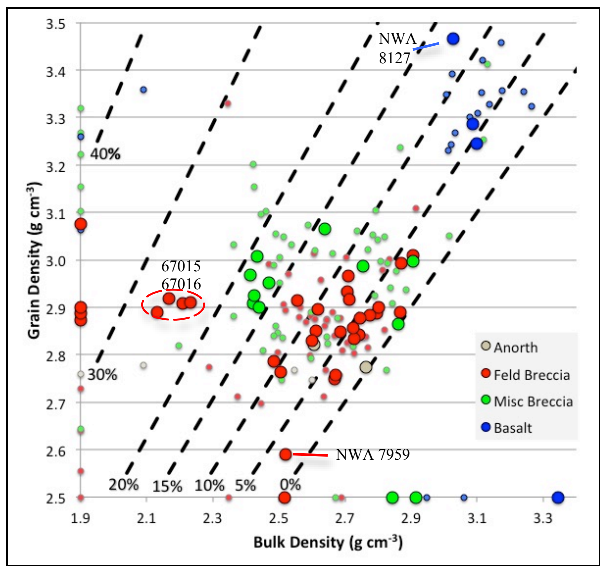

Fig. 1: Grain density vs. bulk density for lunar samples in this study. Large dots represent new data, while small dots are previous data. Dashed black lines are contours of constant porosity. Dots resting on the axes indicate that data for either bulk density or grain density is currently unavailable.

NWA 8127, a purely magnesian olivine gabbro lithology of the NWA 773 clan, has an unusually high grain density of 3.47 g cm^{-3} for a low-Ti lunar mafic rock, and also a high porosity at 12.6%. Note that it is paired with NWA 2977 and NWA 7007, which were previously measured with much lower grain densities (3.25 g cm^{-3}, though one 19-gm piece of NWA 2977 was 3.41 g cm^{-3}) and lower porosities. Though NWA 7007 is from the same meteoroid as NWA 8127, it is a different type of gabbro. NWA 2977 is mineralogically the same as NWA 8127, though it is possible that the measured specimen has some attached breccia.

Martian meteorites: We have new measurements for 12 shergottites, one nakhlite, and one chassignite [Fig. 2]. The chassignite (NWA 2737) is only the second of that type in our database, though technical issues prevent us from reporting densities at this time. Its magnetic susceptibility of log χ = 4.4 (SI units) is much higher than that of Chassigny at 3.98. The newest nakhlite (NWA 10153) is comparable in grain density to other nakhlites, which range from 3.4 to just over 3.5 g cm^{-3}. However, its porosity at 18% is greater than for the other nakhlites measured so far. This is consistent with the unusually high amount of interstitial chlorophaeite in this specimen [10].

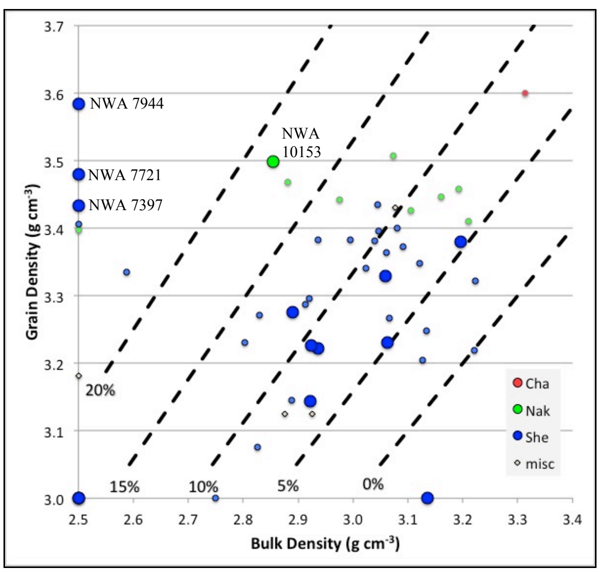

Fig. 2: Grain density vs. bulk density for martian meteorites in this study. Large dots represent new data, while small dots are previous data. Dashed black lines are contours of constant porosity. Dots resting on the axes indicate that data for either bulk density or grain density is currently unavailable.

Most shergottite grain densities among the recent data group with those for the other shergottites in this study between 3.1 and 3.4 g cm^{-3}, lower than those of nakhlites and chassignites. This reflects the greater content of plagioclase (or maskylenite) in the shergottites relative to the chassignites or nakhlites. Whithin the shergottite suite, the grain density is at least partially controlled by the plagioclase (or maskylenite) abundance. Most shergottites have grain densities between 3.2 and 3.4 g cm^{-3}. The trend of increasing density from typical shergottites to NWA 7397 (3.43 g cm^{-3}) and NWA 7721 (3.48 g cm^{-3}) correlates with decreasing plagioclase abundances. The diabasic shergottite NWA 7944 is an outlier, with a high grain density (3.58 g cm^{-3}) and high magnetic susceptibility at log χ = 3.45, compared with log χ = 2.5-3.3 for most other shergottites. The unusual plagioclase-olivine-phyric shergottite NWA 7635 is also an outlier, with log χ = 4.14 and a lower than average grain density of 3.14 g cm^{-3} (although the plagioclase-rich shergottite Los Angeles has a grain density of just 3.08 g cm^{-3}). The elevated magnetic susceptibility of NWA 7635 is not surprising given the high magnetite content of this meteorite.

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